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Occupational Health and Safety in Liquefied Natural Gas Production: A Mini Review Focusing on Ergonomic and Human Factors

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ABSTRACT

As the global liquefied natural gas (LNG) industry grow, the necessity for robust occupational health and safety (OHS) systems increases. This literature review synthesizes OHS research to address the unique challenges of LNG operations. Key findings demonstrate that while current regulatory frameworks are established, the consistent application of human factors engineering (HFE) is often lacking, particularly regarding cryogenic handling and complex maintenance tasks. The review identifies that control room design, fatigue management, and situational awareness are critical areas for mitigating human error. Specifically, the handling of cryogenic materials presents severe risks of burns and asphyxiation, while high-pressure equipment necessitates strict vigilance. It concludes that future resilience in the LNG industry depends on integrating data-driven ergonomic assessment tools with established international standards, such as ISO 11064, to proactively manage risks and optimize human performance. By shifting from traditional behavioral rating systems to sensor-based, machine-learning-enhanced diagnostics, the industry can better address ergonomic hazards and ensure a safe, productive work environment for all personnel involved in complex LNG processing tasks.

Keywords: Ergonomics, Human Factors, Human Factors Engineering, Liquefied Natural Gas, Occupational Health and Safety, Process Safety.

1. INTRODUCTION

Liquefied natural gas (LNG), an important component of the global energy market, is a form of natural gas cooled to about −162°C for transport and storage [1]. Alongside the typical cryogenic risks and major accident risks, large scale, complex maintenance tasks lead to a host of ergonomic challenges [2]. Protecting the health and safety of workers in this area requires a systematic application of ergonomics and Human Factors Engineering (HFE) principles as early as possible in the design process [3]. According to HFE, or Human Factors, it is "the understanding of interactions among human and other elements of a system, and the profession that applies theory, principles, data and methods to design in order to optimize human well-being and overall system performance" [4].

However, the outlined guidance regarding oil and gas applications of HFE over the last 20 years has not been consistently implemented across projects [5]. As such, this review evaluates the OHS situation for LNG production through an HFE framework. The document includes a description of the existing regulatory framework, which is currently being reviewed and an updated set of safety regulations is proposed [6], identification of potential key hazards, a description of the current state of HFE controls, derived findings and recommendations regarding future research and industry practices, thereby supporting the evidence-based ergonomics science in high-hazard workplaces.

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2. METHODOLOGY

This article is a narrative literature review of the occupational health, safety and ergonomics aspects of LNG production. The aim is to synthesise peer-reviewed academic literature, industry documents and regulatory material on occupational health, safety and ergonomics in the LNG sector. A literature search using academic databases Scopus and Web of Science has been performed to capture recent articles, foundational papers in the field of ergonomics and process safety analysis as well as energy engineering. Search terms included: "LNG safety", "human factors engineering", "control room design", "ergonomic risk assessment", "process safety management".

Although the search criteria and methodology draw from recent discipline-specific risk assessments [7] and ergonomics research trends [8], the regulatory scope is centred on the well-established U.S. framework while maintaining a global perspective through relevant international standards. The identified sources were synthesised thematically to create a brief summary of hazards, interventions, and research gaps.

3. THE REGULATORY AND STANDARDS FRAMEWORK FOR LNG SAFETY

Overseeing the safety of an LNG facility consists of a multilayered/multi-agency scheme influenced heavily by industry codes and standards. The principal US LNG facility safety standard is U.S. Department of Transportation 49 CFR Part 193, "Liquefied Natural Gas Facilities: Federal Safety Standards" [9]. Part 193 pre-empts OSHA's Process Safety Management (PSM) standard (29 CFR § 1910.119) for covered facilities and includes performance-based siting, design, construction and operation requirements [10].

Voluntary international standards based on HFE concepts are widely used in the process safety industry. ISO 11064 "Ergonomic design of control centres" is a series of standards that provides guidance to designers of control rooms on ergonomic design principles. It has been identified, particularly in safety-critical and complex process industries (such as LNG), as a way of controlling human error, which is implicated in a meaningful portion of industrial accidents. Safety is also driven by guidelines from organizations such as the International Finance Corporation and operational and safety standards from the American Petroleum Institute (API) that must be used in conjunction with a safety-driven design philosophy.

4. PREDOMINANT HAZARDS: AN ERGONOMIC PERSPECTIVE

LNG operations involve several hazards some of which are closely interrelated and many of which involve human factors. From a human-factor viewpoint, the main hazards of LNG operations are cryogenic materials handling (severe burns and asphyxiation), high pressure equipment and storage of large inventories of flammable materials (fire and explosion) [13]. Heavy physical work in construction and manual handling, in awkward or limited spaces, is particularly associated with MSDs, and with falls and struck by incidents [14].

Human error is common. The continuous operation of complex systems makes particular demands on human performance. These include the loss of situational awareness, due to poor design of control room human-machine interfaces (HMI), poor decision making under pressure, during emergencies and fatigue due to work shift systems and continuous vigilance [15]. As in most other sectors, a large proportion of accidents have a human cause, thus, a human centred design to ensure a safe and productive work environment is critical [16].

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5. ERGONOMIC AND HUMAN FACTORS INTERVENTIONS

These risks can be counteracted through the application of ergonomics to the entire system lifecycle. Since the cognitive heart of the entire LNG facility is within the control room, the design should conform to ergonomics standards such as ISO 11064 to ensure operator efficiency and safety [11]. The basic principles of human-centred design include a structured approach to accommodate user needs, provision of a comfortable and alerting workspace and operating environment, and provision of an effective and efficient Human-Machine Interface (HMI) for each mode of operation [17].

When assessing the physical demands of tasks, a data driven system must be used, as behavioural rating systems such as the Rapid Upper Limb Assessment (RULA) [18] may be subject to the bias of the observer. Data-driven approaches that use sensors in multiple dimensions and machine learning to capture complex body postures and forces at extremely fine granularity have shown promise in automatically scoring and feedback-based workstation redesign [19]. Such systems can provide a scalable solution to address ergonomic hazards in the field.

HFE needs to become an intrinsic part of operational culture, with procedures that are intuitive under pressure, rigorous Fatigue Risk Management Systems (FRMS) and training that integrates non-technical skills, such as situation awareness, communication [20].

6. DISCUSSION

Good human-system performance is critical for the safe operation of LNG facilities. While operational safety performance has benefited from a solid legal-regulatory and technological context, such performance can be improved through the systematic application of human centred design throughout the life cycle of LNG projects.

When HFE standards, such as ISO 11064, have been implemented into industry, they build on decades of experience designing and assessing control room ergonomics [11]. The use of ergonomic big data tools in risk assessment could be used in real-time, enabling proactive design intervention [19]. However, in order to implement these approaches the initial costs, specialist knowledge and levels of end user engagement required at the control room design stages need to be addressed [5].

7. CONCLUSION AND FUTURE WORK

World-class OHS performance in LNG production will require that human capabilities and limitations are recognised as paramount in the design of systems and the management of operations, and ergonomics is considered a core element of engineering design and operational management. To implement these principles to achieve safer outcomes, industry practitioners recommend the following steps be taken. These include the requirement to consider ergonomics throughout all phases of the asset lifecycle from design, through operations and maintenance to decommissioning, and the recognition that retrofitting ergonomics into an asset is more difficult and expensive than if ergonomics is considered from the start.

Implement the use of existing standards, such as ISO 11064-series control room design standards, to ensure that human-centred design principles are applied to all new builds or substantial refurbishments in a consistent, evidence-based way. Pilot and adopt new data-based ergonomic assessment technologies and approaches that complement the observational approaches already in place and provide objective and granular (detailed) perception into the physical ergonomic risk factors involved in complex manual tasks. Building internal competency in HFE, whether by developing internal expertise, or through working with specialist ergonomists, is key to embedding HFE principles credibly and effectively.

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While this review includes most of current knowledge, some areas remain a high priority to advance the state-of-the-art for HFE, such as LNG-specific ergonomics studies in order to accurately predict work-related MSD incidence rates. A controlled study of interventions targeting tasks with the highest volume and risk, such as cryogenic hose handling tasks and heat exchanger servicing, is needed. These should include exoskeletons, tools with updated ergonomics, and task redesign. A better understanding of the return on investment of HFE is also needed; for instance, by case studies of the effect of human-centred design on incident frequency, operational errors, and lifecycle costs.

Further research possibilities exist in the area of suitable human factors models for OHS consistency across multi-level contractor networks in large scale LNG construction projects and turnarounds. Other possibilities involve exploring how to develop and validate AI-based real time health monitoring systems that can measure not only cognitive threats such as fatigue and situational awareness but also assess simultaneous physical ergonomic risks. The LNG industry can show its commitment with building upon these recommendations and identifying gaps, to not only comply with regulations, but to ensure the health and safety of its workforce and the resilience of its critical infrastructure.

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